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⑳ A method of making steel and the use of such method for making steel strip with high strength and formability.

㉑ A method of making steel is provided wherein low carbon steel is heat-treated directly in connection with the hot-rolling to a so-called dual-phase steel the structure of which is characterized by fine-grained, polygonal ferrite and therein dispersed grains of martensite. The mainly in austenitic state hot rolled steel, after finished hot rolling is cooled down to a predetermined temperature within the interval 800-650°C and kept there during more than 1 minute, thereafter cooled to a temperature below 450°C with a cooling rate exceeding 10°C/second. The method is used for making steel strip exhibiting high strength and formability.

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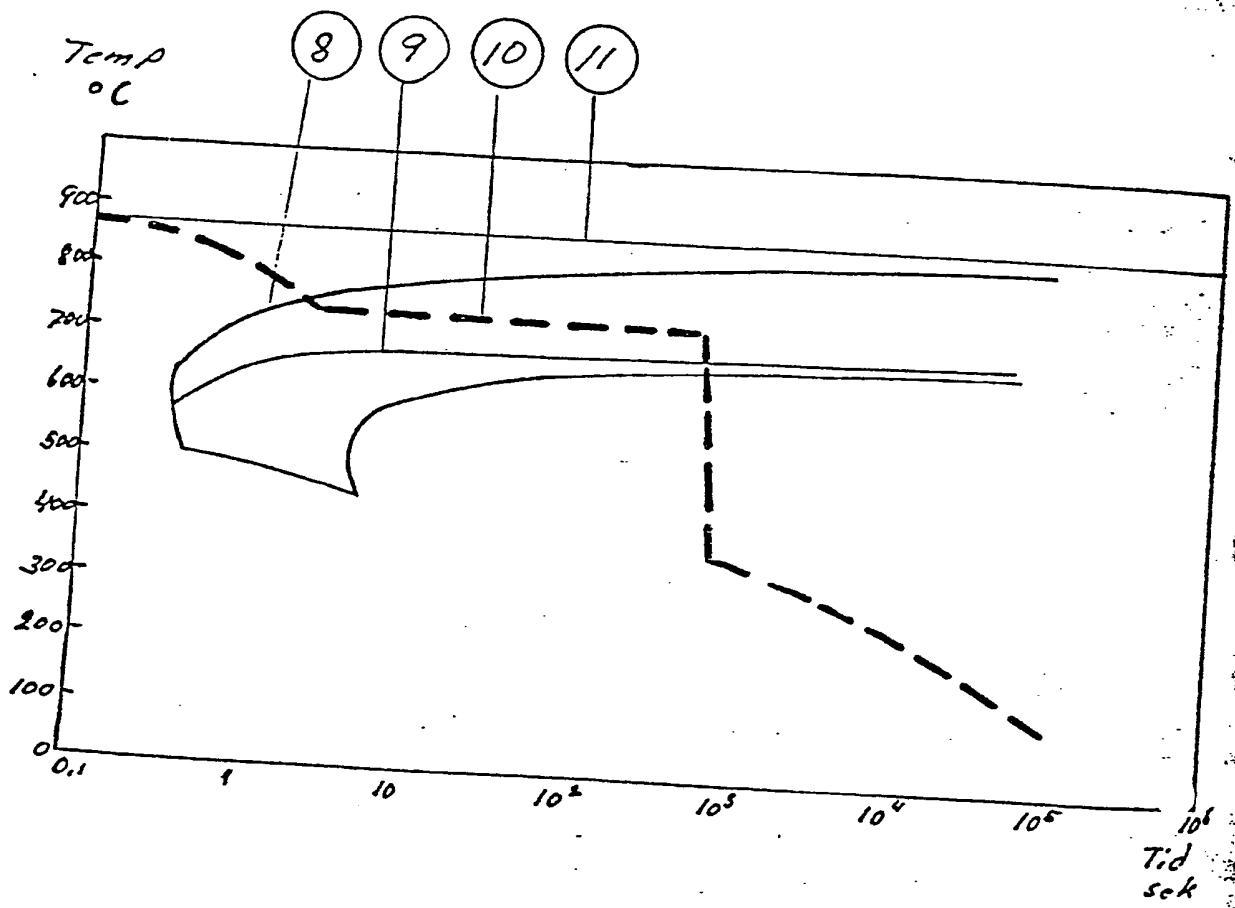


Figure 2

- 1 -

A method of making steel and the use of such method for  
making steel strip with high strength and formability.

This invention relates to a method of making steel with a carbon content of 0.05-0.20 % and a low content of alloying elements so that it is converted to a two-phase steel, containing on the whole fine-grained ferrite and in 5 it dispersed grains of martensite for increasing its ductility and mechanical properties, and the use of such method.

For purposes where high strength as well as good formability are required so-called dual-phase steels have been developed, characterized by a micro-10 structure of fine-grained, polygonal ferrite and in this dispersed grains of martensite. The strength is mainly determined by the amount of martensite and inversely the ductility by the amount of ferrite. The tensile strength thus varies approximately between 400 and 1,400 MPa, the elongation between 40 and about 10 % when the amount of martensite increases from 5 % to 25 %.

15 To develop this structure in a steel strip an annealing treatment can be practised, involving heating to a temperature above the transformation point  $A_1$  in the iron-carbon diagram (usually to about 750°C), followed by quick cooling from this temperature, attained by water spraying or blowing with cooling-gas. The annealing involves considerable costs, as it on one hand requires energy 20 on the other presupposes a technically complicated equipment.

A method to avoid these extra costs is to make such alloying additions that with a suitably elaborated cooling the structure desired is obtained directly in hot-rolled condition. Such a method is described in the Swedish patent application 7711926-1. The advantage with this is that no heat treatment 25 is needed after the rolling, but instead fairly expensive alloying additions have to be done, among others of 0.4 % Mo. Further it is both expensive and troublesome to arrange such a powerful cooling after a modern hot-strip mill with high rolling velocity.

It has now been shown, that a very good dual-phase steel with good strength 30 and formability properties can be obtained by coiling the steel hot after the hot-rolling (possibly preceded by a certain primary cooling) and after that cool down the steel according to a pre-set cooling scheme. The method is especially suitable for steels with approximately the following composition:

5	C	0.05 - 0.20 %
	Si	0.50 - 2.0 %
	Mn	0.50 - 1.5 %
	Cr	0 - 1.5 %
	V	0 - 0.15 %
	Mo	0 - 0.15 %
	Ti	0 - 0.04 %
	Nb	0 - 0.02 %

The carbon content is chosen according to desired tensile strength.

10 The content of Si, Mn and Cr is chosen according to the thickness of the rolled products; the thicker the product, the higher content of these elements is required. The lower values are approximately valid for 1.5 mm strips, the higher for 8 mm strips.

15 One or more of the elements V, Mo, Ti and Nb can be used to obtain fine-grained austenite after the hot-rolling and by that fine-grained ferrite. This can be specially motivated for thicker strips (over 5 mm).

20 To improve the formability of the steel further in the transverse direction, the amount of elongated sulphide inclusions should in well-known manner be reduced, either through the addition of misch-metal (REM-treatment), through the addition of small amounts of tellurium or through keeping the sulphur content well below 0.010 %.

25 The invention which is defined closer in the attached patent claims, shall here be described more in detail in connection with the figures enclosed, of which figure 1 in schematic form shows an example of a hot strip mill and figure 2 a CCT-diagram for the group of steel in question and with a schematically drawn example of a cooling sequence according to the invention.

30 The steel is finished to strips in the ordinary manner (7), e.g. in a continuous hot strip mill (1). In doing so the heating temperature and other parameters are adjusted so that the finishing temperature after the hot strip mill (1) is between 750 and 900°C. Normally it is desirable to keep the finishing temperature in the lower part of the range, but higher strip thicknesses and other factors can make it necessary to accept higher finishing temperatures.

35 The strip (7) then passes a first cooling line (2) and is coiled on a first coiler (3). In the cooling line (2) the temperature of the strip (7) is slightly lowered. After coiling the temperature of the strip (7) namely has to be between 800 and 650°C and in this range on a level, which is optimal for the structure with regard to desired strength. Optimal means in this connection most favourable for the precipitation of fine-grained ferrite out

of austenite, which takes place below the ferrite transformation curve (8) in figure 2; at the same time it must be above the level of the pearlite transformation curve (9) where the residual austenite begins to transform into pearlite. The curve (10) drawn in the CCT-diagram, figure 2, exemplifies 5 a thinkable cooling course.

When the whole length of the strip thus has been coiled on the first coiler (3) at the predetermined temperature the coil is transferred to a transport device, roller conveyer, wagon etc. for further forwarding to a recoiler (4). During this transport the coil is covered with a heat insulating 10 envelop, which minimizes the heat losses and above everything counteracts local cooling of the outer parts of the strip (7). To the transport time is added the delay-time required to allow a desired amount of ferrite to form.

When coiling off from the recoiler (4) the strip is led through a second cooling device (5) and thereafter coiled on the second coiler (6). The cooling 15 is so adapted to the strip velocity that the strip, when it runs up on the second coiler (6) has a temperature between 450 and 300°C, at which the lower temperature is valid for steel with low content of alloying elements, especially Si and the higher temperature for steels with higher contents of such elements.

By the cooling the transformation of austenite to pearlite and bainite is 20 suppressed, particularly that to upper bainite. This is instead transformed at lower temperature to martensite. Smaller amounts of low-temperature bainite can also be accepted without deteriorating the properties of the material.

The slow cooling in the coil after recoiling at the second coiler (6) is favourable in order to attain a low yield point, as it allows the carbon dis- 25 solved in the ferrite to precipitate. If however a precipitation hardenable material is wanted the cooling can be driven to a lower temperature (below e.g. 100°C) before the strip is coiled on the second coiler (6). The steel can then after forming be given increased yield point by precipitation hardening of the carbon retained in supersaturated solution in ferrite during a tempering treat- 30 ment at about 200°C.

In the description above the temperature ranges by coiling on the first coiler (3) are set to 800 - 650°C and preferably 750 - 650°C. These temperature ranges are dependent on several demands:

a) The ferrite shall be precipitated in the finest dispersion possible, 35 as the fine-grain structure contributes to high strength as well as high ductility. This is favoured by a high supersaturation at the transformation, i.e. the strip should after the finishing rolling as quickly as possible be cooled down sufficiently below the transformation temperature  $A_3$  (the line (11) in figure 2) to start a transformation with a high nucleation rate. The

temperature shall on the other side not be so low that the main part of ferrite has not time to precipitate in the equiaxed (polygonal) form before the next cooling step.

To obtain the intended ductility the amount of ferrite precipitated in this way in polygonal form must constitute at least 80 % of the amount of proeutectoid ferrite precipitated from the same steel by slow continuous cooling from the austenite range (e.g. in furnace), counted as surface percent in a metallographic section. Partically this means that the coiling temperature must be so much below the transformation temperature  $A_3$  for the steel in question that the range for ferrite precipitation in the CCT-diagram valid for the steel is reached fairly quickly, exemplified in figure 2. An upper limit can with regard to this be set at a temperature  $100^{\circ}\text{C}$  below the transformation temperature  $A_3$ . For the steel according to figure 2  $A_3$  can be set to about  $870^{\circ}\text{C}$ .

b) The lower limit of the interval is determined by the requirement that the austenite shall not in considerable degree start transforming into pearlite. In steels actual for the method, and the composition of which is specified above, the formation of pearlite is displaced towards lower temperature and longer time in relation to the formation of ferrite. With regard to this the lower limit is set to  $A_1$  minus  $50^{\circ}\text{C}$ , i.e. in this case about  $670^{\circ}\text{C}$ .

A more exact determination of the optimal temperature interval for a certain steel during its transferring from coiler (3) to coiler (4) can thus be done by determining the transformation characteristics for the steel in a CCT-diagram, foremost the ferrite transformation curve (8) and the pearlite transformation curve (9), through heat-treatment in laboratory-scale. The temperature where the remaining austenite is substantially transformed into pearlite is then valid as the lower limit for the interval inside which the coiling and cooling from the coiler (4) must take place.

EXAMPLE 1

30 A test which shows that with the method here described even with very low content of alloying elements very good strength properties can be obtained, is described below.

The steel had the following analysis:

35	C	0.15 %
	Si	0.91 %
	Mn	0.63 %
	N	0.006 %
	A1	0.03 %

the rest is Fe including normal impurities.

It was rolled to 10 mm thickness. For laboratory scale suitable specimens of this material were treated as follows:

1. Heated to  $900^{\circ}\text{C}$
2. Quickly transferred to a salt bath furnace at  $725^{\circ}\text{C}$  and held there for 10 minutes
3. Transferred to another salt bath furnace at  $350^{\circ}\text{C}$  and held there further 10 minutes
4. Thereafter allowed to cool in air

The following mechanical properties were obtained:

Yield point	$R_e$	412 MPa
Tensile strength	$R_m$	574 MPa
Elongation	$A_5$	34 %

This combination of high tensile strength and high elongation is characteristic for dual-phase steel.

#### 15 EXAMPLE 2

Experimental ingots were hot-rolled from a thickness of 120 mm down to 160 mm wide strips with a final thickness of 3 mm. Finishing temperature was around  $850^{\circ}\text{C}$ . The strips were directly cooled with water sprays to a (simulated) coiling temperature  $T_c$  which varied from 765 to  $725^{\circ}\text{C}$  depending upon the com-  
20 position of the particular steel, and were thereafter kept in a furnace held as the temperature  $T_c$  for various periods of times, then again cooled with water sprays to below  $400^{\circ}\text{C}$  and finally from there on in air. Tensile tests were taken from the strips and values for proportionality limit  $R_{.2} \%$ , yield stress at 2 % strain  $R_{2.0}$ , fracture stress  $R_m$  and elongation  $A_5$  determined.

25 The results are shown in the following table:

Material Code	Analysis				Coiling temp. $T_c$ $^{\circ}\text{C}$	Holding time min.	Mechanical properties			
	% C	% Si	% Mn	% Cr			$R_{.2}$ MPa	$R_{2.0}$ MPa	$R_m$ MPa	$A_5$ %
30 42 B N	.08	.85	.90	.93	750	5	311	454	616	29
43 A D	.08	.93	1.32	.51	725	10	361	501	655	26
43 B A	.08	1.22	1.29	.51	725	5	321	466	660	26
42 A H	.08	.87	.93	.93	765	10	306	442	623	28

In all cases the stress strain curve was rounded and showed no sign of yield point elongation. It may be noted that the increase in yield strength for the first two % of plastic strain is around 140 MPa for all four materials.

Claims:

1. A method of making steel with a carbon content of 0.05-0.20 % and a low content of alloying elements so that it is converted to a two-phase steel, containing on the whole fine-grained ferrite and in it dispersed grains of martensite for increasing its ductility and mechanical properties, characterized by the fact that the mainly in austenitic state hot rolled steel after finished hot rolling is cooled down to a predetermined temperature within the interval 800-650°C and kept there during more than 1 minute, thereafter cooled to a temperature below 450°C with a cooling rate exceeding 10°C/second.
- 15 2. A method according to claim 1 characterized by the fact that the predetermined temperature lies in the interval 750-650°C.
- 20 3. A method according to claim 1 and 2, characterized by the fact that the strip (7) after hot-rolling and cooling in a first cooling device (2) to a predetermined temperature is coiled on a first coiler (3) whereafter the coil is kept heat insulated until the intended amount of ferrite has been precipitated and then cooled in a second cooling device (5).
- 25 4. A method according to claim 1-3, characterized by the fact that the time the material is kept at the predetermined temperature is adjusted so that at least 80 % of the amount of ferrite normally formed during slow cooling through  $A_1$  has time to precipitate.

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5. A method according to claim 1-4, characterized by the fact that the cooling in the second cooling-line (5) occurs so quickly that at most 5 % of the amount of austenite remaining at the beginning of the cooling is transformed to pearlite.

6. The use of a method according to any one of the preceding claims for making steel strip with high strength and formability on basis of steel having a carbon content of 0.05-0.20%, Si 0.50-2.0 % and Mn 0.50-1.5 % and Cr, V, Mo, Ti and Nb as optional constituents.

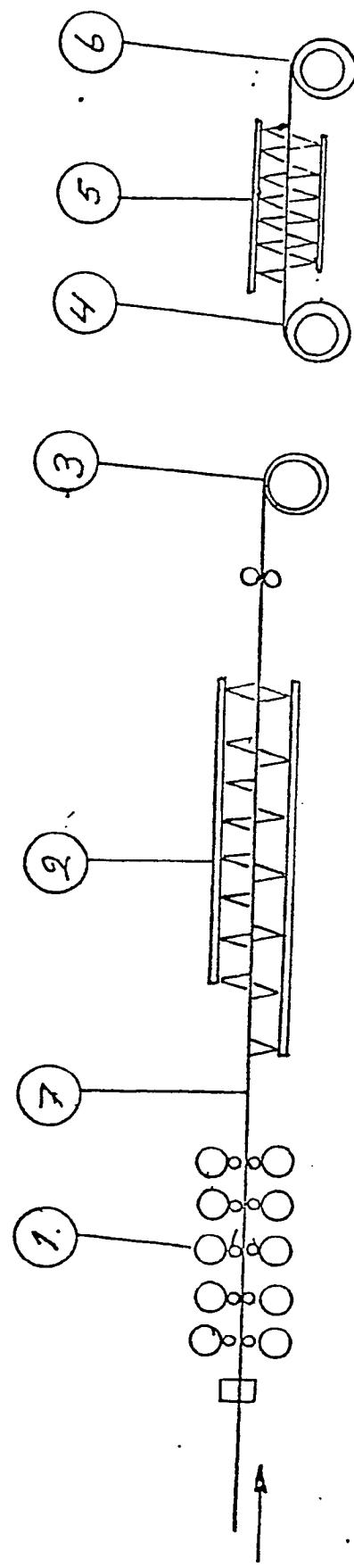
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Figure

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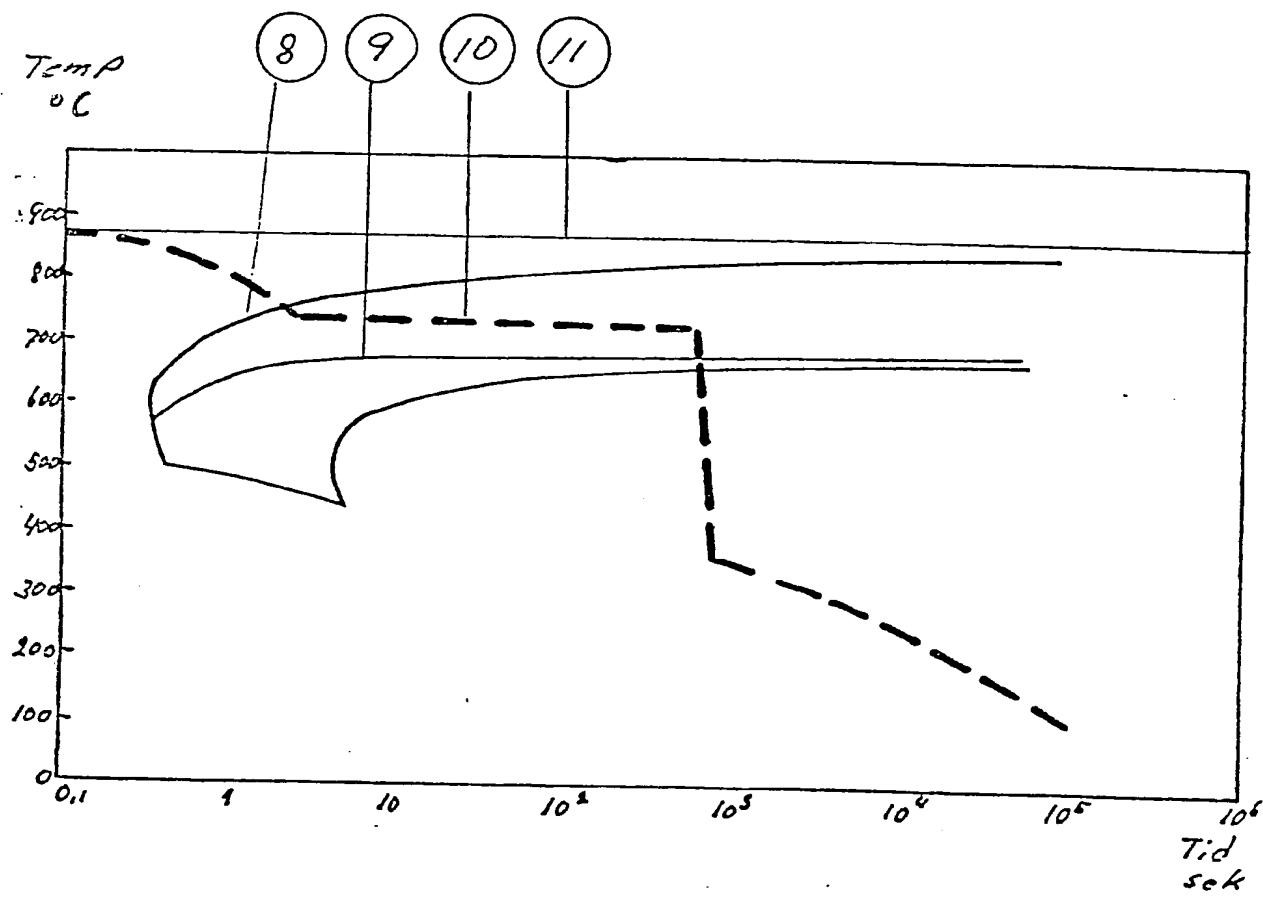


Figure 2

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int.Cl.¹)
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	
X	<p>GB - A - 1 333 876 (STAHLWERKE SUDWESTFALEN)</p> <p>* Claim 1 *</p> <p>---</p> <p>PATENTS ABSTRACTS OF JAPAN, vol. 2, no. 126, 21st October 1978, page 2684C78</p> <p>&amp; JP - A - 53 95121</p> <p>* Whole content *</p> <p>---</p> <p>JOURNAL OF METALS, vol. 30, no. 3, March 1978, pages 16-19 New York, U.S.A.</p> <p>J. MORROW et al.: "Molybdenum in intercritically annealed dual-phase steel strip"</p> <p>* Whole content *</p> <p>---</p>	1,2,4, 5	C 21 D 8/02 8/00 1/18
P	<p>PATENTS ABSTRACTS OF JAPAN, vol. 3, no. 87, 25th July 1979, page 110C53</p> <p>&amp; JP - A - 54 65118</p> <p>* Whole content *</p> <p>---</p>	1,6	TECHNICAL FIELDS SEARCHED (Int.Cl.²)
P	<p>ZEITSCHRIFT FUR METALLKUNDE, vol. 71, no. 1, January 1980, pages 27-31 Stuttgart, DE.</p> <p>J. BECKER et al.: "Dualphasen-Gefüge"</p> <p>* Figure 7b *</p> <p>---</p>	1	C 21 D
A	US - A - 4 072 543 (A.P. COLDREN et al.)	----	CATEGORY OF CITED DOCUMENTS
			<p>X: particularly relevant</p> <p>A: technological background</p> <p>O: non-written disclosure</p> <p>P: intermediate document</p> <p>T: theory or principle underlying the invention</p> <p>E: conflicting application</p> <p>D: document cited in the application</p> <p>L: citation for other reasons</p>
			<p>&amp;: member of the same patent family, corresponding document</p>
<p><input checked="" type="checkbox"/> The present search report has been drawn up for all claims</p>			
Place of search	Date of completion of the search	Examiner	
The Hague	25-08-1980	MOLLET	